ARPES Studies of the Fermi Surface in $Bi_2Sr_2CaCu_2O_{8+\delta}$: hole or electron-like?

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INTRODUCTION

Over the past decade, Angle-Resolved Photoemission Spectroscopy (ARPES) has become one of the most powerful tools for understanding the physics and electronic structure of high temperature superconductors (HTSCs). Among the normal state properties of HTSCs, the Fermi Surface (FS) topology is one of the most important since it needs to be determined prior to correctly predicting many physical properties. Most of our information about the FS topology of HTSCs has come from ARPES studies of Bi-Sr-Ca-Cu-O (BSCCO), and the results have been widely interpreted as a hole-barrel centered around the (π,π) or X(Y) points of the Brillouin zone, as illustrated in figure 1(a)[1-3]. However, this conclusion was made mainly by using incident photon energies around 21eV[2]. Recently we have shown that the physical picture appears quite different when measured using 33eV photons — there is a strong depletion of spectral weight around the (π,0) point and the FS appears to have electron-like portions, as shown in figure 1(b)[4]. This result has been recently confirmed by Feng et al.[5].

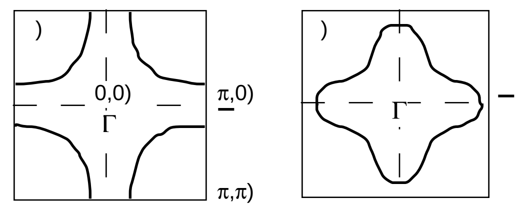

Figure 1. Hole-like FS topology (a) versus electron-like topology (b).

This new interpretation of ARPES data on BSCCO has come into question by two experimental groups in four recent papers[6-8]. To further study this issue, we have carefully probed the momentum-space region around (π,0) using the ultra-high energy and momentum resolution ARPES facilities at the ALS. We have analyzed this data in a number of ways, all of which give results consistent with the 33eV FS which we originally proposed[4].

EXPERIMENTAL

We used the High Energy Resolution Spectrometer (HERS) endstation at Beamline 10.0.1 to perform the experiments, operating the Scienta SES 200 energy analyzer in angle mode. This allowed us to simultaneously collect 89 individual spectra along 14 degree wide angular slices. The angular resolution of the measurements was about ±0.08 degrees along the slice (θ direction) and about ±0.25 degrees perpendicular to the slice (ϕ direction). Energy resolution was better than 10meV at 10K. The data shown here is from an overdoped $Bi_2Sr_2CaCu_2O_{8+\delta}$ sample (T_c=79K) which was cleaved and measured in the normal state at 100K. During measurements the base pressure was maintained below 4 x 10^{-11} torr.

RESULTS

Panels (a) and (b) of figure 2 show a two dimensional color scale plot of the spectral weight at E_F, i.e. $A(k,E_F)$, plotted as a function of θ and ϕ near the (π,0) or (Mbar) region of the

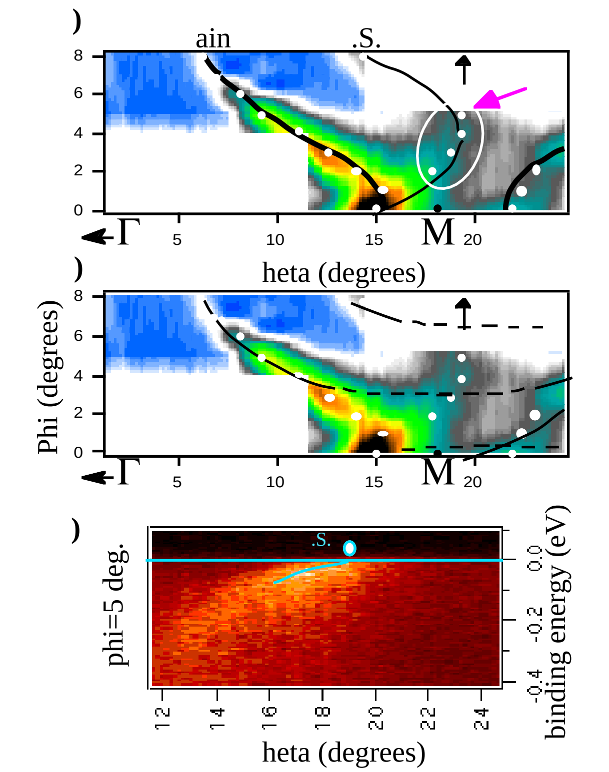

Figure 2. Panels (a) and (b) are plots of spectral weight from a 50meV window centered on E_F. White dots are FS crossings determined from dispersion. The FS topologies overlaid are (a) electron-like and (b) hole-like. Panel (c) in the angle mode data collected at $\phi=5$. Horizontal axis is θ angle along the 14 degree slice, and the vertical axis is binding energy. The location of the FS crossing is indicated by the white dot.

Brillouin zone. The plot was obtained by integrating the spectral weight of Energy Distribution Curves (EDCs) over a 50meV window centered on E_F. On this plot the FS should show up as the region of maximum spectral intensity. The white dots are the FS crossing points determined by looking at the dispersion in the EDCs. In panel (a) we have overlaid the FS experimentally determined from this data. The thick black lines represent the main FS, while the thin lines represent the superstructure (S.S.) derived FS obtained by shifting the main FS by $(0.2\pi,0.2\pi)$ along the Γ - Y direction. The FS determined here is qualitatively and quantitatively (to better than 5%) the same as that determined in reference[4].

In contrast, panel (b) shows the hole-like FS topology taken from Fretwell et al.[6] overlaid on the data. The hole-like FS extends toward $(\pi,0)$ while the data does not. Fretwell et al.[6] attempted to reconcile this by empirically introducing a strongly momentum-dependent matrix element effect to drastically reduce the weight near $(\pi,0)$, indicated on the plot by dashed sections of the FS. Despite the extra free parameters introduced by this assumption, the hole-like FS still cannot match the curvature of the high intensity portion near $(\theta,\phi)=(14,2)$. Also the hole-like FS has trouble accounting for the portion of the FS naturally explained by the S.S. band in panel (a) (the part circled in white). To show the quality of our data in this region, we have included some EDCs which show the S.S. band FS crossing at $(\theta,\phi)=(19,5)$ (indicated by the arrow in panel (a)). Panel (c) shows a false-color plot of EDCs obtained with $\phi=5$ degrees fixed. The horizontal axis is the θ angle along the 14 degree slice, and the vertical axis is binding energy. The plot shows a feature dispersing in energy as a function of angle until it reaches E_F at which point it disappears due to the FS crossing. As a guide to the eye we have overlaid a blue curve on top of the data to track the dispersion of the S.S. band up to E_F. This is a strong FS crossing which simply cannot be explained by the hole-like FS topology.

The increased energy and momentum resolution of the data in figure 2 brings up other subtleties that have not previously been observed. Looking at the high intensity locus of the main FS in figure 2, a drop in intensity occurs near $(\theta,\phi)=(14,2)$. This makes the FS appear as if it has two components, one nearer to the $(0,0)-(\pi,\pi)$ line and one nearer the $(0,0)-(\pi,0)$ line. Further study needs to be carried out to understand the separation of the FS into these components, as well as to study potential differences in the behavior of each component.

Finally, of course, there is the critical issue of connecting the electron-like FS topology observed at 33 eV with other topologies observed at other photon energies. Our new high resolution data as well as older lower resolution data [4,5] have shown that both the electron-like and hole-like topologies can be observed on a single sample simply by varying the photon energy. A natural possibility is to consider coherent three-dimensional band structure effects (possibly even from the z^2 band), although this would need to be reconciled with the highly two-dimensional nature of the cuprates. Even-odd splitting between the CuO_2 bilayer may produce both an electron and a hole like FS in the same sample, although this would need to be reconciled with the single-layer Bi2201 data which also appears to show both topologies[4]. Two FS's may simultaneously exist in the same sample for other reasons as well, for instance due to phase separation into hole-rich and hole-poor regions or into regions with and without stripe disorder [5] each of which may produce its own FS portions. Within these scenarios we still need to understand why one piece of the FS is accentuated at one photon energy while another is accentuated at another. Matrix element effects may play a role in this [9].

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